A Two-year Comparison of Spawning and Spat Settlement Cycles in Blue Mussels (*Mytilus edulis*) from a Salmon Farm and its Implications for Integrated Multi-trophic Aquaculture (IMTA) in the Bay of Fundy.

T.R. Lander, S.M.C. Robinson, J.D. Martin and B.A. MacDonald.

Fisheries and Oceans Canada
Science Branch, Maritimes Region
St. Andrews Biological Station
531 Brandy Cove Road, St. Andrews, NB
E5B 2L9

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A Two-year Comparison of Spawning and Spat Settlement Cycles in Blue Mussels (*Mytilus edulis*) from a Salmon Farm and its Implications for Integrated Multi-trophic Aquaculture (IMTA) in the Bay of Fundy

by

T.R. Lander, S.M.C. Robinson, J.D. Martin and B.A. MacDonald.

Fisheries and Oceans Canada
Science Branch, Maritimes Region
St. Andrews Biological Station
531 Brandy Cove Road, St. Andrews, NB E5B 2L9

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ABSTRACT

Lander, T.R., Robinson, S.M.C. Martin, J.D. and MacDonald, B.A. 2010. A two-year comparison of spawning and spat settlement cycles in blue mussels (*Mytilus edulis*) from a salmon farm and its implications for Integrated Multi-trophic Aquaculture in the Bay of Fundy. Can. Tech.Rep. Fish. Aquat. Sci. 2848: vi + 24 p.

Annual reproductive cycle of the blue mussel, *Mytilus edulis*, from a commercial aquaculture site in Bocabec Bay of Fundy, New Brunswick, was investigated for an eighteen month period from 2001 to 2002 to assess predictability in annual spawning and spat settlement cycles – factors important when considering the implementation of mussels as a commercial crop at current salmon growing operations in the Bay. Spawning commencement and duration proved comparable for both years analyzed, with spawning inception in May, followed by pulsed rather than continuous spawning activity persisting throughout the summer period, concluding on September 2001 and August 2002. Larval duration lasted between four and six weeks for both years. Subsequent settlement increased steadily, with peak settlement intensity being reached in August for both years, although small numbers of settled individuals were found into November and December, perhaps as a result of delayed settlement or byssal drifting juveniles. Mean tissue loss in the adult mussels, used as a spawning indicator, was less in 2002 compared to 2001, yet an 87% increase in settlement was seen in that year compared to 2001, perhaps as a function of increased fertilization success, larval survival, or an increase in migration from other areas in that year. Results indicate that within a single site, reproductive timing can be predictable, but yearly fluctuations, due to both exogenous and endogenous factors may affect exact timing and the subsequent seed collection for commercial use.

Key words: Blue mussel, *Mytilus edulis*, spawning, settlement, integrated multi-trophic aquaculture.

RÉSUMÉ

Lander, T.R., Robinson, S.M.C., Martin, J.D. et MacDonald, B.A. 2010. A two-year comparison of spawning and spat settlement cycles in blue mussels (*Mytilus edulis*) from a salmon farm and its implications for Integrated Multi-trophic Aquaculture in the Bay of Fundy. Rapp.tech. can. sci. halieut. aquat. 2848: vi + 24 p.

Le cycle annuel de reproduction de la moule bleue, la *Mytilus edulis*, dans un site aquacole commercial de Bocabec, dans la baie de Fundy au Nouveau-Brunswick, a été le sujet d'une étude de dix-huit mois, de 2001 à 2002, dont l'objectif était d'évaluer la prévisibilité du frai et des cycles annuels de fixation des larves. Ce sont des facteurs importants lorsque l'on veut évaluer l'intégration des moules en tant que culture commerciale dans les sites actuels de salmoniculture de la baie. Le début et la durée du frai sont comparés pour les deux années d'analyse. La formation du frai commence au mois de mai, suivi par un frai pulsatile et non continu tout au long de la période estivale, se terminant en septembre 2001 et en août 2002. La vie larvaire a duré entre quatre et six semaines pour les deux années. La fixation qui a suivi s'est accrue de façon constante. Son pic de fixation a été atteint en août pour les deux années, bien qu'un petit nombre d'individus déposés a été trouvé en novembre et en décembre. C'est peut-être le résultat d'une fixation retardée ou de juvéniles à la dérive du byssus. En 2002, la perte moyenne de tissu chez les moules adultes, que l'on utilise en tant qu'indicateur de frai, était inférieure à celle de 2001, bien qu'une augmentation de la fixation de 87 % a été observée en 2002, par rapport à l'année précédente. Il s'agit peut-être d'une fonction du succès accru de la fécondation, de la survie des larves ou d'une migration accrue à partir d'autres zones au cours de cette année. Les résultats démontrent que sur un même site, le calendrier de reproduction peut être prédit, mais les fluctuations annuelles causées par des facteurs exogènes et endogènes peuvent influencer le calendrier exact et donc le captage des naissains à des fins commerciales.

Mots clés : Moule bleue, *Mytilus edulis*, frai, fixation, aquaculture multi-trophique intégrée.

INTRODUCTION

One of the dominant organisms on rocky shores in most temperate areas, blue mussel (*Mytilus edulis*) populations also occur sub-tidally. A unique aspect of such sub-tidal populations involves constant exposure to food supplies and consequent capacity for continuous growth, allowing individuals to attain large sizes in relatively short periods of time (Page and Hubbard 1987). The ability of sub-tidal populations to grow rapidly has led to the development of fixed, suspended cultivation of the blue mussel world-wide. However, such mussel cultivation has not been established in the Bay of Fundy, mainly due to human safety issues associated with seasonal shellfish toxicity as well as seasonal sea duck predation.

Recently, an interest in mussel culture in the Bay of Fundy has been fuelled by a study designed to investigate the potential for integrated multi-trophic aquaculture (salmon-mussel-kelp) in the area. The study will provide the only information of its kind on the development of integrated, sustainable aquaculture systems in the southwest Bay of Fundy region, and whether benefits, (both environmentally and economically), can be achieved via co-cultivation of species. As opposed to implementation of a separate long line system, integrated aquaculture would involve the implementation of compact floating rafts directly adjacent to pre-existing salmon cages, from which mussel socks would be suspended.

Such suspended mussel culture relies on the collection of small mussels ("seed" or "spat") on either rope or plastic collectors set out for the purpose (Scarratt 1993). The natural availability of seed sources (without the need of hatchery production), has been a significant positive factor in the development of mussel farming. However, such an advantage is not without uncertainty, as much of a mussel farmer's effort is expended obtaining sufficient sources and quantities of seed. The timing of this effort must take into account the reproductive cycle of the animal: timing of gonad maturation, spawning, larval planktonic phase, as well as settlement and metamorphosis of the juvenile mussels, in order to accurately predict seed set and eventual collection. Knowledge of settlement timing and intensity is of particular interest for the grower as future production of market sized mussels is contingent on a dependable seed source. Collection of local seed can also circumvent the need to import spat from other areas, lessening financial load for growers and the probability of introduction of new diseases and invasive species into an area. Also, since mussels are considered a substantial fouling organism for current salmon culture operations, an additional benefit of knowing the seasonal spatfall timing provides salmon growers with an early warning system when planning net cleaning schedules.

The objective of this study was to investigate the reproductive cycle of wild adult *Mytilus edulis* growing sub-tidally at Atlantic Silver, Inc., an operational salmon aquaculture site located in Bocabec Bay, Bay of Fundy, New Brunswick. Timing and duration of mussel spawning, as well as larval period and spat settlement intensity was monitored for an 18 month period from May 2001 to December 2002, to assess whether the timing of such events was predictable on an annual basis. Such knowledge could not only facilitate an ease of transition into mussel culture for potential growers at the study site itself, but outline techniques whereby such information can be gathered in any region, as it is the issues of seed availability which must first be addressed by any new mussel grower. Note - although two separate species of Mytilus (*M. edulis and M.*

trossulus) are known to inhabit this area of the Bay of Fundy, for ease of analysis all settled spat were referred to as *M. edulis* for the purpose of this paper.

MATERIALS AND METHODS

MUSSEL SPAWNING EVENTS

Sampling Protocol

At two week intervals from May 2001 to December 2002, 30 adult mussels (> 50 mm shell length) were collected from a population growing beneath an unused PVC ring (formerly used for attachment and buoyancy of a salmon net), at Atlantic Silver aquaculture site in Bocabec Bay (45° 08'.240 N, 67°01'.671 W), Bay of Fundy, New Brunswick. At each sampling the PVC ring was raised using a vessel mounted crane (Fig. 1) and the exposed mussels were sampled randomly. Mussels were held on ice in sealed plastic bags and transported to the St. Andrew's Biological Station where laboratory analysis commenced.

Laboratory Analysis

Mussels were de-clumped and the byssal threads of attached conspecifics as well as fouling organisms were scraped from the shells of each mussel. Byssal threads of the sample mussels were excised with scissors. Shell morphometrics (length, width and height) of each mussel were taken with digital calipers (to 0.01 mm, Fig. 2), and exported directly into an Excel ™ spread sheet using Collect XL ™ software. Whole closed weight of each mussel was taken using a digital scale (nearest 0.01 mm). A scalpel was then inserted between the two shell valves, and a lengthwise incision was made from anterior to posterior severing both the anterior adductor and pallial retractor mussels, thereby exposing the body cavity and associated tissue. Each mussel was blotted on paper towels after which an opened drained weight was taken using a digital scale (to the nearest 0.01 gram, Fig. 3). Each mussel was sexed and spawning stage noted as immature, ripening, ripe, spawning, spent (adapted from Seed 1969), via visual inspection of the gonads. Whole body tissue was separated from the shell using a scalpel (Fig. 4 and 5), and then weighed, and dried to constant weight at 80° C in pre-weighed aluminium pans (Fig. 6). Dry meats and shells (after a 48 hour air-drying period) were weighed to the nearest 0.01 gram.

Data Analysis

Change in dry mussel tissue yield, used as a spawning indicator, was assessed for all mussels per sample. A combined mean was calculated for each sampling period and plotted temporally to illustrate the degree of spawning (measured as a loss in body tissue), its timing and seasonality, as well as recovery period post-spawn.

$$\text{Dry Tissue Yield} = \frac{\text{dry tissue weight}}{\text{dry tissue wt + dry shell wt.}} \times 100 \qquad (1)$$

Student's t-tests were performed comparing mussel length and pre-spawning dry meat yields from 2001 and 2002 to assess whether there were any significant differences (using $\alpha = 0.05$ significance level) in these growth parameters between years.

MUSSEL SPAT SETTLEMENT

Sampling Protocol

In May 2001, six 5 m polypropylene lines were deployed vertically along existing site boundary ropes of the Atlantic Silver site to quantify timing and degree of mussel spat settlement. Ropes were spaced ~1m apart and weighted at the ends using 0.23 kg lead weights to minimize tangling. One mesh panel (200 cm^2, polyethylene with a 6 mm mesh size) was tied and at 2, 3 and 4 meter depths on each rope [n = 6 panels for each depth, (Fig. 7 and 8)]. At two-week intervals, the panels, with associated settled flora and fauna, were collected from the vertical ropes and replaced with new ones. The vertical lines remained fixed until the end of the experiment in January 2003.

Laboratory Analysis

Panels were bagged individually according to rope number and depth and transported to the lab on ice. Settled organisms were removed from the panels via washing into a 30 cm PVC pipe with 100µm mesh bottom to facilitate collection (Fig. 9). The mussel spat from each panel were separated from other settled organisms, placed on a gridded petri dish and enumerated under a dissecting scope (Fig. 10 and 11).

Data Analysis

Mean total settlement intensity was calculated by averaging settlement over all depths and panels for each sampling date. The 6 panels from each depth (2, 3 and 4 m) were further averaged to determine settlement stratification by depth. All means were plotted temporally to determine commencement, duration and cessation of settlement activity at the site. Settlement cycles were compared for the 2001 and 2002 seasons to address questions of similarity in timing and duration from year to year.

ENVIRONMENTAL VARIABLES

Water Temperature

Water temperature was measured year round using a Vemco™ minilog thermograph deployed at 5m depth on collector rope #3. The thermograph was programmed to obtain one temperature reading at 30 minute intervals, and was replaced with a new unit prior to memory depletion to ensure continuity of temperature data. Mean daily temperatures were calculated from interval data and plotted. Degree days from January 1 to May 31 (period prior to spawning) were calculated for both 2001 and 2002 by totalling the mean daily temperatures over the period.

Salinity/Fluorescence

Water salinity and fluorescence readings were collected using a Seabird-19 CTD™ water column profiler. Fluorescence readings were used as an indirect measure of water column chlorophyll a content. Profiles were collected directly adjacent to the collector ropes. Sampling dates were identical to those of mussel and panel collections. Readings between 2 and 6m (area above the pycnocline), were averaged and the mean values plotted with time. Measurements at one meter were not used due to irregularities caused by surface freshwater input at various intervals during the year.

RESULTS

MUSSEL SPAWNING EVENTS

Sampling of adult mussels commenced on May 8th, 2001 and coincided with the maximum dry meat yield (24.1 g, Fig. 12) for the year. During the next two weeks mean dry yield fell to 16 grams, a loss of 33 % over that interval. By July 6, mean dry tissue yield dropped to its minimum (8.9 g), after which no further reduction was observed. Following the initial 33% decrease, dry yield increased slightly again to 17.7 g at the next sampling, before reaching the lowest level. Overall, a decrease of 63.1% in dry tissue mass was seen over the spawning period. Dry tissue weights began to increase directly after spawning, with small fluctuations (from min.10.67 g to max.13.2 g) through to October, after which it rose quickly to 23.4 g by October 9, 2001, suggesting a recovery from the spawning season was complete. Mean mussel shell length for 2001 was 64.3+/- 7.8 mm standard deviation.

The 2002 spawning cycle differed somewhat from the previous year. From October 2001 to May 2002 the mean dry tissue yield remained relatively constant, with only a slow decrease over the period. A tissue loss of 21% (from 20.3 g to 16 g) occurred between May 22 and June 3, 2002 (Fig. 12), after which, the yield increased to a pre-spawn level of 21.2 g on June 10, indicating a significant increase in body tissue over this interval. This was immediately followed up by an interval during which there was a 39% decrease in dry tissue yield, dropping to a low of 12.6 by August 19, 2002, again perhaps correlating to a termination in spawning. As in 2001, dry tissue yield increased steadily post-spawn, with a few slight fluctuations. At the termination of

the experiment (December 6, 2002), mussels had recovered to a pre-spawn level comparable to the previous year. Mean mussel shell length for 2002 was 68.2 +/- 7.8 mm standard deviation.

A negative correlation was found when mean dry tissue yield was plotted against mean daily water temperature. In 2001, the coefficient of determination (r^2 values) between these two parameters was found to be 0.44 and in 2002 it increased to 0.63 (Fig. 13). Corresponding coefficient of correlation values (r values) were calculated to be 0.66 for 2001 and 0.79 for 2002.

Results of the student's t-test comparing mean mussel shell lengths for 2001 and 2002 show that there was a significant difference ($t = -3.85$, $p = 0.013$) in the lengths of the mussels collected in the two years (64.3 +/- 7.8 mm sd in 2001 versus 68.2 +/- 7.8 mm sd in 2002). T-test results comparing maximum dry yield values from mussels collected prior to first spawning events in 2001 and 2002 show the dry yield in 2001 to be significantly higher than in 2002 ($t = 2.55$, $p = 0.0001$).

MUSSEL SPAT SETTLEMENT

Mussel settlement commenced in July 2001 with very small amounts of spat present on the panels early in the month (mean of 3.5 spat per panel, all depths combined). By July 17, mean settlement had risen to 234 spat per panel. Settlement peaked in late August during the 2001 season. By August 30 a maximum of 8,466 mussel spat were present per panel. Subsequent samples saw a rapid decrease in spat numbers, although a sparse number were present (0.7- 1.3 individuals per panel) until January, 2002, a fact not evident in Fig. 14 due to scale.

In 2002 settled mussels were first observed on panels from the early July sampling, with a mean of 127 spat per panel (all depths combined, Fig. 14). Settlement intensity increased rapidly over the next 6 weeks, reaching peak settlement during the August 12, sampling where mean spatfall reached 13,644 individuals per panel (all panels combined, Fig. 14). All ensuing samples saw a decrease in spat numbers, with the last individuals of the season being collected at the November 5th sampling (mean settlement of 3 individuals per panel), after which no further settlement was seen.

A comparison of the 2001 and 2002 settlement cycles (Fig. 14), indicate that while settlement commencement dates were similar for both years, intensity and duration of set differed considerably with year. In 2002 peak settlement occurred two weeks earlier than in 2001 (August 12th as compared to August 30th in 2001), with an overall mean of 39% more individuals present on combined collectors when compared to peak settlement in the previous year. During the post-peak settlement period, spatfall decreased more rapidly in 2002 with a reduction of 90% during following sampling (13,643 individuals versus 1,027 individuals per panel). The 2001 mussels declined less dramatically, with only a 56% drop at next sampling (8,465 versus 3,644 individuals per panel). However, relatively high numbers of spat were present on 2002 collectors into the month of October (overall mean of 345 spat), while only 15 spat per panel had been seen in 2001. There were no spat present after the November sampling in 2002, while small numbers of spat were collected from the 2001 season into January of 2002.

When spatfall commenced in 2001, mean spat numbers did not deviate with collector depth until August 1st sampling, when there was 25% fewer spat per panel at 4m compared to those at 2 and 3 meters respectively (2,316 individuals versus 3,116 and 3,066, Fig. 15). Over the remainder of the settlement cycle, greater numbers of individuals settled at 4 meter depth than at 2 or 3 meters. At peak settlement intensity, a mean of 11933 individuals had settled at 4 meters, with only 8,090 at 3 meters and 5,373 at 2 meters.

The 2002 settlement cycle proved similar to 2001 in terms of depth trends. At first sampling, slightly more spat had settled at 3 m than 2 or 4 meters (158 versus 88 and 133 individuals). During peak settlement there was a mean of 14,338 individuals per panel at 4 m compared to 12,960 at 2m and 13,631 at 3m. At each subsequent sampling there were slightly more individuals found at 4 m than at 2 or 3 meters, until settlement ceased in mid November 2002 (Fig.15.)

During the 2001 experimental period (May to December), a cumulative total of 177,552 mussel spat were collected from the site. Figure 16 illustrates total spatfall broken down by depth for the year - 41,419 (2m), 57,751 (3m), and 78,382 (4m). Cumulatively, 2002 saw an overall settlement increase of 87% over the previous year with 332,338 individuals being collected. Depth wise increases of 124% at 2m (93,024 individuals), 93% at 3m (111,520), and 63% at 4m (127,794), were observed over the previous year (Fig. 16). Although panels were collected over a 12 month period in 2002, compared to an 8 month sample duration in 2001, the period between January and April, 2002 no settlement was observed, making total numbers (from May to December of each year) directly comparable.

Using external gonad examination as an indication of spawning stage, 100% of the mussels sampled in 2001 were actively spawning by the June 7th (Fig. 17). However, during previous sampling (May 23rd), all of the mussels sampled were noted as ripening, and had not yet developed fully ripe gonads. Therefore, during the period from May 24th to June 7th, the mussels became ripe and began releasing gametes. A majority of mussels (>50%) remained in the spawning stage until the October 9th sample, with 45% actively spawning until Oct. 22nd. Therefore, the duration of the 2001 spawning season was approximately 20 weeks.

Ripe individuals were seen in 2002 during the April 29 and May 31 samplings (Fig. 18). By June 3rd 2002, 91% of sampled mussels were actively spawning. Thus, spawning commenced during the period of May 31st and June 3rd. During the October 7th sampling, 39% of mussels were actively spawning. Subsequent sampling dates found no further spawning individuals. The spawning season therefore ended between Sept. 5th and Oct. 7th, hence, a 12 week (min.) to 16 week (max.) spawning season for 2002.

ENVIRONMENTAL VARIABLES

Mean daily water temperature on July 6th 2001 (date of first settlement) was 11.5°C. In 2002 settlement began on July 8th when mean daily water temperature was 11.4°C (Fig. 19). In both years settlement continued through a period of maximum yearly temperatures for the site (16.8°C –August 5th, 2001; 18.1°C- August 17th, 2002) and into the fall. Settlement concluded

for the 2001 season after January 9th, 2002, when mean daily water temperature was 3.8°C. In 2002 settlement ended after the November 5th sampling where mean daily water temperature was at 7.9°C. The number of degree days from January 1st to June 1st, ascertained by totaling the mean daily temperatures over this period for both years, was found to be 421 in 2001 with an increase to 554 in 2002.

Salinity values at the experimental site were not collected during the 2001 season. However, during the 2002 season salinity values ranged from a minimum value of 30.15 psu (practical salinity units), on May 6th, 2002 to a high of 32.5 psu on November 15, 2002, a fluctuation of 2.35 psu over the 10 month experimental duration (Fig. 19).

Relative chlorophyll a concentrations (combined mean of 2-6 m depths) peaked during mid July in 2001 (Fig. 19, 7.18 µg/L) and stayed reasonably constant until dropping significantly after the Oct. 9th sampling. By mid November the concentration had reached to 2.82 µg/L and further lowered to 2.32 µg/L in late December, the lowest reading for that year. In 2002 the lowest yearly concentration reading occurred in early April (2.55 µg/L), but rose quickly to 9.93 µg/L by May 22nd. A corresponding drop in early July (to 2.93 µg/L), was followed by a second peak, after which levels remained above 7 µg/L until mid November. At experiment termination (December 2002), levels had once again risen to 6.11 µg/L (Fig. 20).

Spring tides occurred from June 4-6th in 2001 and June 9-11th in 2002 in Bocabec Bay.

DISCUSSION

Unlike hatchery-based aquaculture systems, which rely on land–based early rearing facilities, the success of mussel culture operations are largely dependent on the availability of a natural seed source. Current interest in mussel culture in the Bay of Fundy raises fundamental questions regarding seed procurement for commercial use. If salmon growers are to convert existing monocultures to a multi-trophic condition incorporating the blue mussel, they must first become familiar with collection techniques and settlement cycles of mussels in their area. Information pertaining to such mussel reproductive biology in the Bay of Fundy is currently lacking. This report examined blue mussels at an operational salmon aquaculture operation in Bocabec Bay, New Brunswick to evaluate aspects of the reproductive biology and spat settlement patterns of a local mussel population.

Although the reproductive cycle in *Mytilus edulis* has been studied extensively, only a partial understanding of the complex interactions between exogenous (e.g. temperature, food, salinity) and endogenous (e.g. nutrient reserves, hormonal cycle) factors, which control initiation and duration of spawning and larval settlement, exists today (Seed and Suchanek 1992). Of the exogenous factors, sea temperature and food supply appear to be particularly important. Newell et al. (1982), demonstrated larval abundance in Long Island Sound, New York, USA, to be highly correlated to food availability. Podniesinki and McAlice (1986), in analyzing an 8 year data set from Damariscotta River in Maine, suggest the trigger for spawning was the occurrence

of spring tides and a subsequent increase in seawater temperature to 10-12.5 °C, with a corresponding autumn drop to 14°C, as the threshold below which spawning activity ceased. Similarly, spawning commencement in *Mytilus edulis* has also been correlated to a rise in seawater temperature to 10-12°C in southwest Iceland (Thorarinsdöttir 1996). However, in a more recent study by Thorarinsdöttir and Gunnarsson (2003), 35% and 87% of mussels sampled from two different Icelandic fjords were found to be actively spawning in July when sea surface temperatures ranged between 4 and 7 °C. The maximum sea surface temperature of 10.1 °C was not reached in their study until weeks after initiation of spawning in July. In the present study, using loss of overall body mass as a spawning indicator, we can infer that spawning began in early May in 2001 and late May 2002, at temperatures between 4 and 6 °C, temperatures consistent with the findings of Thorarinsdöttir and Gunnarsson (2003). It is important to note that the mean site temperatures were collected at a depth of 5 meters using a thermograph, while mussels were collected just below the water surface growing on an abandoned salmon cage. Using the 5 meter data would perhaps be an under-estimation of surface temperature as temperatures tend to diminish with depth. It is possible that a combination of warm spring temperatures and calm sea conditions could have occurred in early May which allowed surface temperatures to be higher than those recorded at 5 meter depth. Such an increase would not have been recorded by the thermograph at 5 meters. This theory is further supported by temperatures taken at the site on May 6, 2002 when the surface temperature was found to be 7.5°C; while at 5 meters the mean daily temperature was 5.3°C. It is therefore possible that a temperature cue played a role in spawning initiation at this site. Once spawning commenced, an overall clear negative relationship between water temperature and dry yield variables is apparent for both years, and undoubtedly is a function of loss due to spawning throughout the spring and summer period when water temperatures are increasing. A calculation of degree days (using data collected at a 5 meter depth) for the period prior to spawning (January 1st to May 31st) indicated that there was an increase of 133 degree days in 2002 over the previous year. This suggests the period immediately preceding first spawning was warmer in 2002 than 2001, yet spawning initiated earlier in 2001 than 2002. It appears as though degree days play less of a role in spawning initiation than fine scale changes in temperature.

Chlorophyll values increased significantly in May 2001, a similar trend was not seen in 2002, thus, it cannot be concluded that an increase in food availability in the form of phytoplankton was the impetus to mussel spawning activity in this study. It should be noted that chlorophyll values were recorded only twice a month and finer scale fluxes in food availability may have been overlooked. Also, the contribution of anthropogenic food sources cannot be ignored, and may in fact play an important role. *Mytilus edulis* is a generalist consumer and has been known to exploit such food sources (Stirling and Okumus 1995). Elevated levels of particulate organic matter have been observed year round, up to 500m away from salmon aquaculture sites (Brzeski and Newkirk 1997), which offer a high nutrient food source for the mussels growing adjacent to salmon sites. It is possible that a combination of allochthonous food sources, when augmented by anthropogenic sources from the site itself, may have played an important role in spawning initiation in the study mussels. If this is the case, growing mussels in proximity to salmon cages may not only prove beneficial for growth but also for reproduction, and eventual seed procurement for commercial use.

In the present study, an initial reduction in body mass occurred during early May in 2001. Upon visible inspection, it was apparent that mussels had begun to expel gametes from the gonad tissue, suggesting that the loss in body weight was likely directly due to spawning. A slight increase in body mass in June and subsequent secondary loss suggests a spawning period that is incremental rather than continuous. This is consistent with Seed and Suchanek (1992), who state that during the spring months a period of partial spawning is followed by gametogenesis until the gonads are once again ripe. The authors go on to state that the second period of gametogenic activity is more evident, as it occurs during a period of more favorable feeding conditions. The mussels examined in this study appear to follow this trend. The serial nature of spawning is also supported when looking at settlement cycle, where periods of moderate settlement were followed later by a period of maximum settlement, possibly due to increased reproductive output later in the season. A similar trend has been demonstrated by Newell et al. (1991), where two spawning peaks in late spring resulted in bimodal settlement peaks in early and late July in Maine. In this study, there is also an indication that two smaller spawning events may have occurred in late August and early September 2001 as suggested by the weight loss-gain-loss trend. If this assumption is valid, spawning ended by mid September in 2001. The initial cycle in 2002 was similar to that of 2001 with an initiatory tissue weight loss in May (again, gonad inspection indicated mussels were actively spawning) during this period, directly followed by a gain (more pronounced than in 2001), and then a final loss. However, there appeared to be no further losses and gains as detected in late summer 2001. Therefore, spawning ended during mid August in 2002.

Statistical tests reveal the dry tissue yield in pre-spawn mussels in 2001 was significantly higher than pre-spawn mussels in 2002. As more precise gonadal-somatic indices (those which relate the amount of reproductive and non-reproductive tissue) were not performed, it is unclear as to whether an increase in overall dry yield in 2001 was a result of increased reproductive tissue in 2001 or merely a function of the increased overall size of the mussels which were 2.89 mm larger than those collected in 2002.

Despite the fact that overall mean tissue loss was less than the previous year, peak settlement yielded 38% more individuals per settlement panel in 2002. This may have been a function of increased larval survival due to a change in food quantity or quality, or increased fertilization success, as it appears actual reproductive effort (in terms of percent change in tissue mass), was lower during that year. It is unlikely that an increase in settlement was directly due to salinity or temperature changes, as the data from both years indicate both temperature and salinity to be similar and well within the range of normal larval development, settlement, and metamorphosis in this species (Bayne 1965). However, the chances of increased larval survival and settlement due to changes in food cannot be dismissed. The fact that *Mytilus edulis* can exploit anthropogenic food sources, such as those available around salmon aquaculture sites has already been established via tracer studies (Mazzola and Sara, 2001). Such an augmentation to natural food supply has been demonstrated to promote enhanced growth in this species when grown adjacent to salmon cages (Wallace 1980; Jones and Iwama 1991; Lefebvre et al. 2000), where an anthropogenic food supply provided via lost and un-utilized salmon feed particles, is readily available and can be utilized by the mussels (Mazzola and Sarà 2001). Therefore, an increase in larval survival and subsequent spat settlement in 2002 may possibly be related to an increase in salmon food administered to the site in 2002. In 2001 the site was newly stocked with

salmon smolt, which increased in size over the next year with a corresponding increase in the amount of food being administered to the fish as they grew. An increase in food administered, will cause a subsequent increase in particle losses to the surroundings, in turn, augmenting available food supply for the larvae provided they are a utilizable size. This may have played a role in the settlement differences between 2001 and 2002 assuming the larvae remained in the vicinity of the farm in both years.

In both 2001 and 2002 mussels were found on collectors in December and November respectively. Such delayed settlement can either be a function of late spawning pulses and subsequent settlement, or due to byssally drifting juveniles – individuals who pass through a secondary pelagic phase during which they detach from their original substrate and may attach to and detach from several substrates before permanent attachment (Lane et al. 1985).

Previous studies indicate that normal growth to metamorphosis and settlement for *Mytilus edulis* at 10°C takes one month (Seed, 1976; Lane et al. 1985). When back calculating the difference between initial drop in gonad yield and first settlement, we find that for the 2002 season, the larval duration was between 6-8 weeks in length.

Although the onset of settlement was similar for 2001 and 2002, the intensity differed somewhat. In 2002 there were greater numbers of individuals at all samplings compared to similar periods during the previous year, except at peak settlement in 2001. During this same interval, settlement had nearly ceased in 2002. A comparison of peak settlement indicates a two week spread between years. This could be understood better in terms of sampling schedule. Since spawning activity was a function of dry tissue change over two week intervals, there was no way of determining the exact onset of spawning for each year. It is possible that the commencement of spawning occurred immediately prior to the mussel sample in which a distinct decrease was noted in 2001, and up to 13 days prior to sampling (i.e. immediately after the previous sampling) in 2002. Such a difference could account for the spread between years, indicating a 4 week larval period for 2001, not the 6-8 week larval period as seen in 2002. Alternately, decreased larval period can be a function of environmental cues. Bayne (1965) states that when salinity, temperature, food supply, and other factors are optimal, larval development of *M. edulis* may be completed in 20 days or less.

If the data presented in this paper are indicative of future settlement trends at this site, it appears the period to deploy collector to achieve maximum settlement is mid to late August. During this time collectors should be monitored frequently as fouling organisms as well as starfish predators have similar settlement cycles. Attempts in 2002 to obtain maximum spat yield proved futile as ropes were deployed early in the season (date during which settlement had commenced the year previous), and left too long in the water column. Subsequently, ropes laden with spat early on were heavily fouled with filamentous green and red algae by peak settlement period. While several previous papers indicate that mussels settle readily on previously settled filiform algae (Bayne 1965; Lane et al. 1985), results from this study indicate that algal settlement post mussel set may be deleterious to mussel settlement. This finding is consistent with Penney (1993), who determined that timing of spat collector placement should coincide as closely as possible with spat settlement, to avoid algal growth prior to settlement which can reduce settlement and displace previously settled spat.

Scarratt (1993), in an analysis of northern mussel culture, indicates that the depth of maximum spatfall is generally the upper two meters of the water column. The data collected via this study show maximum settlement at a depth of 4 meters. Although 4 meters represented the lowest collector depth in this study, it remains unclear whether this is the depth of maximum set for the study area, or whether collectors at increased depths would show increased settlement intensity. At any rate, it appears as though mussel farmers in the study area would benefit substantially from collectors extending beyond the 2 meter depth.

Success of any mussel farm depends, in no small part, on a dependable, locatable, and quantifiable source of spat. The advantages of procuring a local seed source has been discussed previously, and involve understanding the reproductive and settlement cycles of local populations. However, such knowledge can only be ascertained via regular site monitoring. When sites are monitored, growers are better able to predict the time of spawning, larval duration, time of settlement and optimum locations and deployment times for collectors (MacNeill et al. 1999). Regular monitoring can also predict changes in the above criteria on temporal scales, so changes can be recognized early and adapted for. Finally, regular monitoring can reveal settlement patterns of fouling organisms and predators.

This study has shown that within a single site, settlement trends can be relatively predictable from year to year. However; yearly fluctuations exist perhaps as a function of an interaction of exogenous and endogenous factors. Therefore, each potential mussel grow-out site must be treated as unique, with reproductive cycle and spatfall monitoring executed regularly over several years in order to gather enough information to maximize annual spat yield and subsequent commercial grow out.

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FIGURES

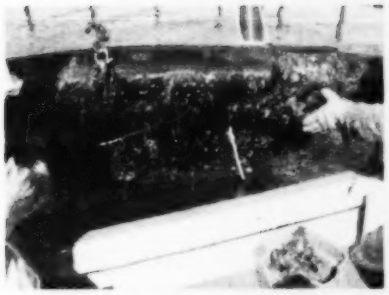

Figure1: Collection of blue mussels from un-utilized salmon cages at Atlantic Silver salmon farm.

Figure 2: Measurement of mussel morphometrics using a digital caliper.

Figure 3: Measuring opened, drained weight for each mussel.

Figure 4: Division of mussel body tissue from shell.

Figure 5: Numbered wet shells and associated body tissue ready for drying.

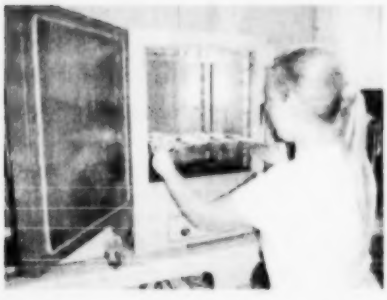

Figure 6: Mussel tissue is dried in a convection oven at 80 degrees for 48 hours.

Figure 7: Two-week old spat collection panel at the study site in Bocabec Bay, N.B.

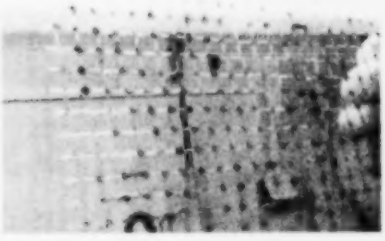

Figure 8: Close-up of settlement panel with newly settled blue mussel spat and associated species.

Figure 9: Settled spat from collection panels are removed via washing and collected onto 300μm sieve.

Figure 10: Blue mussel spat are isolated onto a grided petri dish and enumerated using a dissection microscope.

Figure 11: Blue mussel spat of varying ages isolated from a single settlement panel during August 2001 (viewed at 4x magnification).

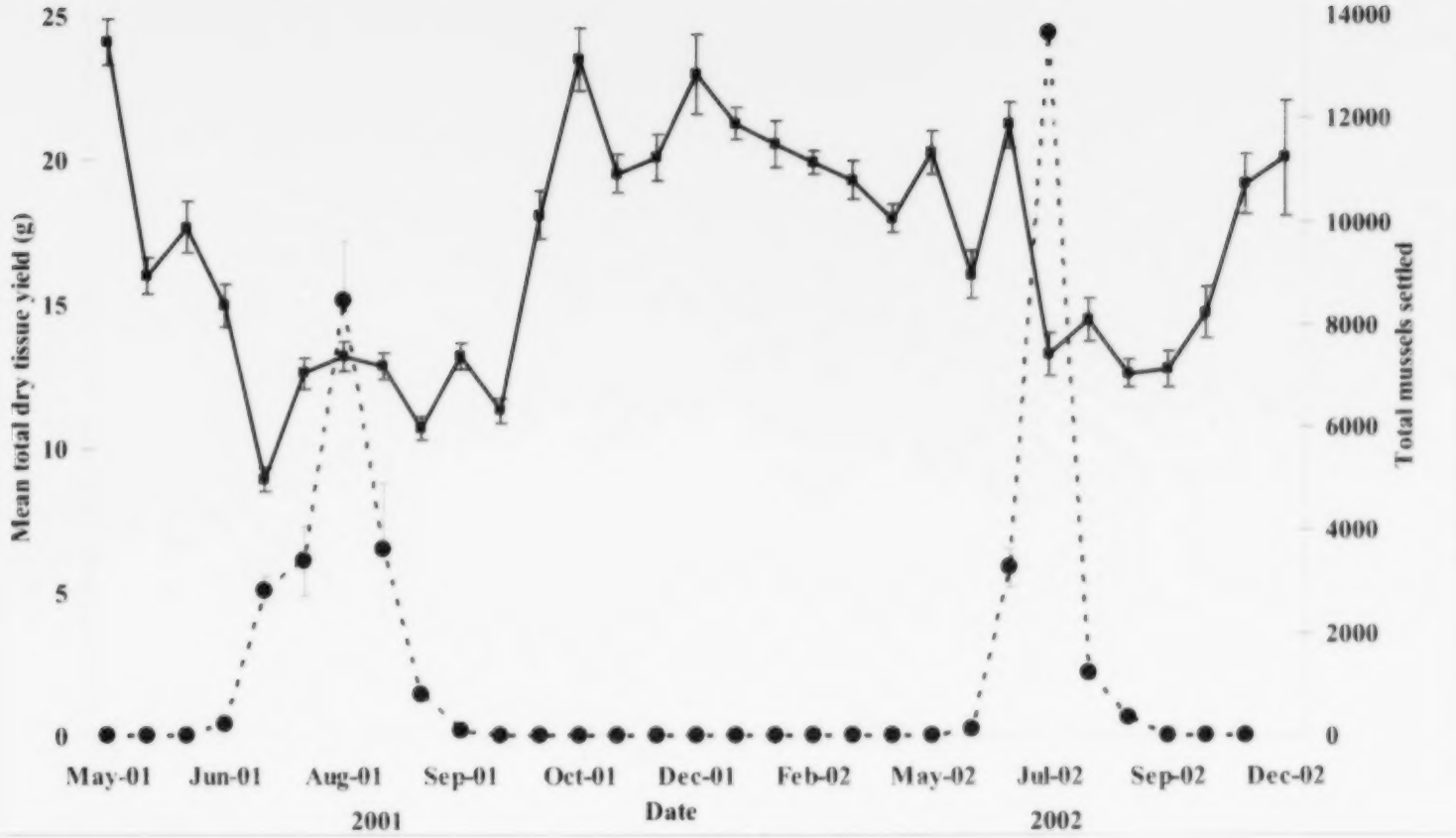

Figure 12: 1.Change in mean dry tissue yield (solid line) of adult mussels (> 50mm SL) collected at Atlantic Silver aquaculture site in Bocabec Bay, Bay of Fundy, NB over an 18 month period from 2001 to 2002. Error bars represent one standard error. 2. Total numbers of settled blue mussel spat (all collectors, all depths- dashed line) at Atlantic Silver aquaculture site in Bocabec Bay, NB over an 18 month period from 2001 to 2002. Error bars represent one standard error.

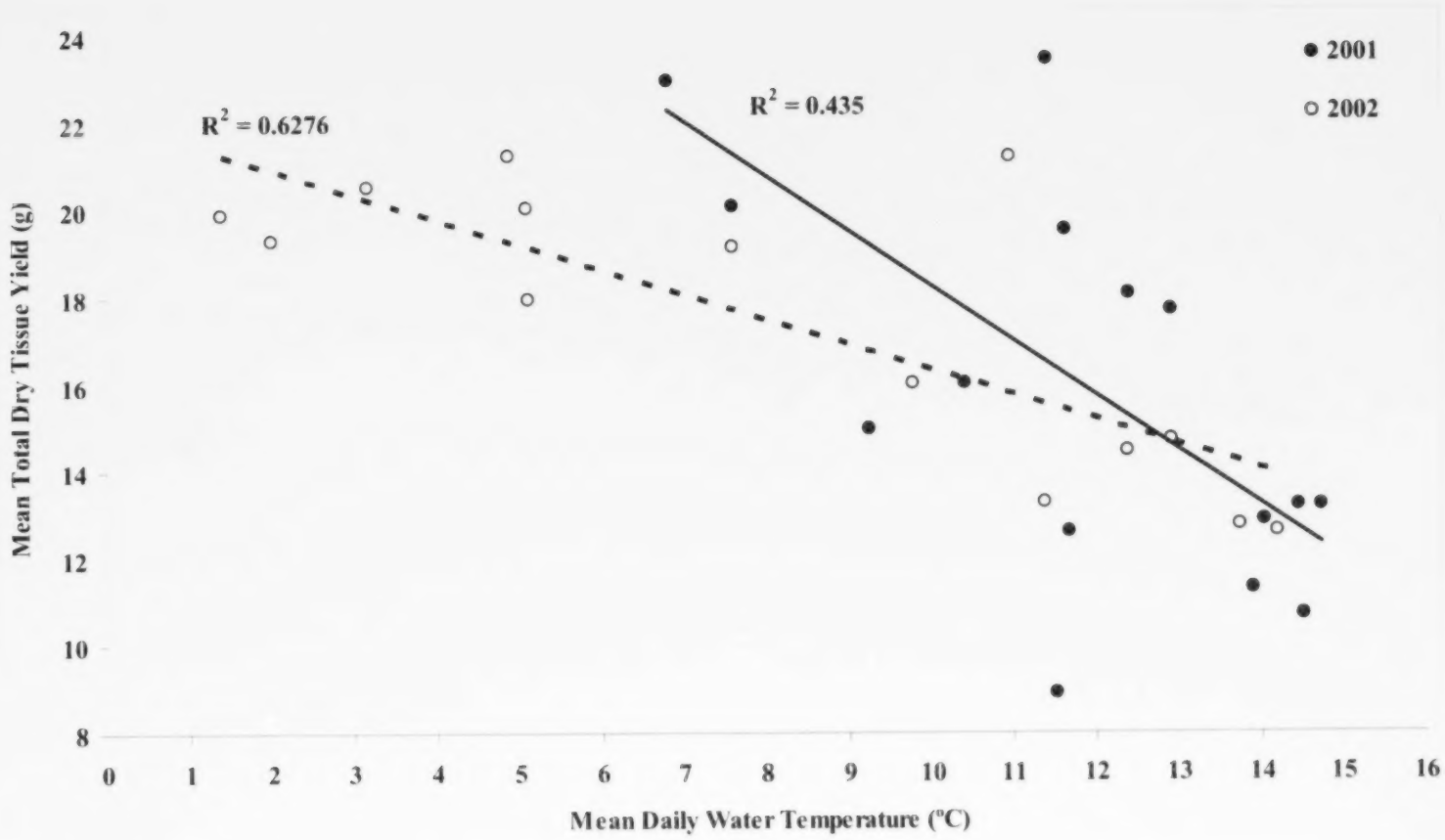

Figure 13: Correlation of mean daily water temperatures from 2001 and 2002 taken at the Atlantic Silver aquaculture site and mean total tissue yield for mussels collected from the site.

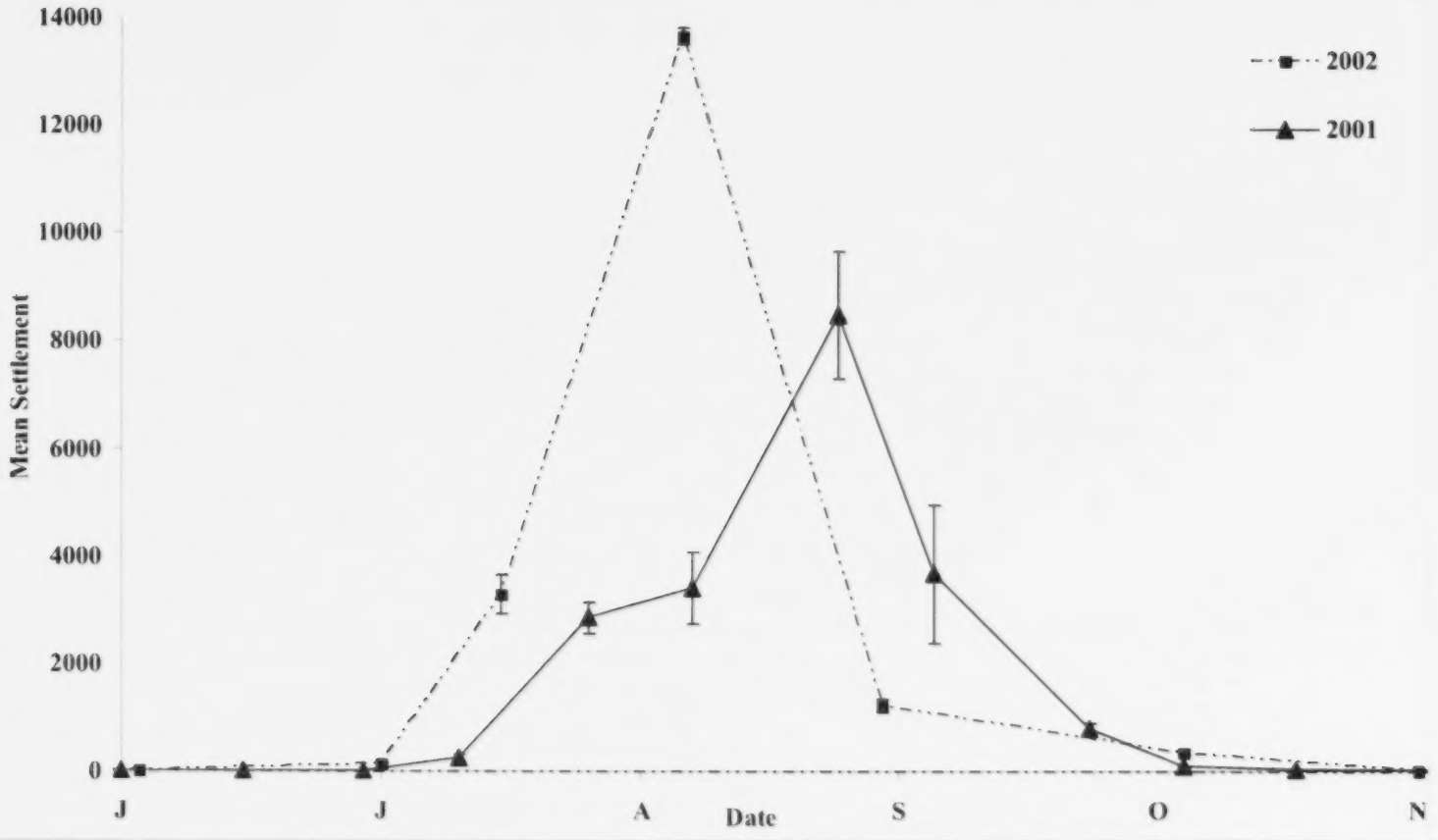

Figure 14: A comparison of blue mussel settlement cycles in 2001 and 2002 at Atlantic Silver (values are a mean of all collectors at all depths). Error bars represent one standard error.

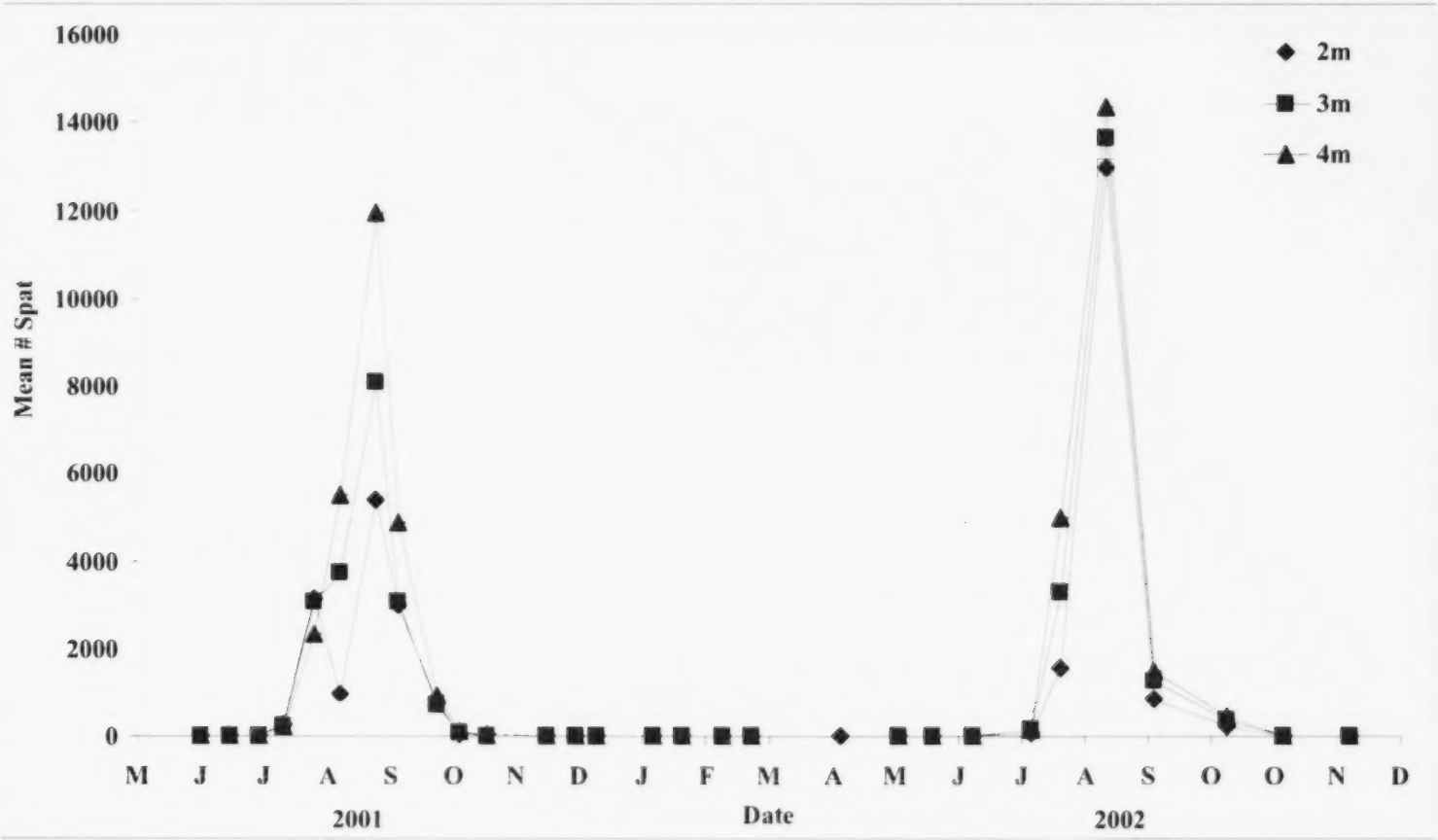

Figure 15: Yearly spat settlement cycle at depths 2, 3 and 4 meters at Atlantic Silver aquaculture site, Bocabec, NB. Mean of all collectors (n = 6) at each depth.

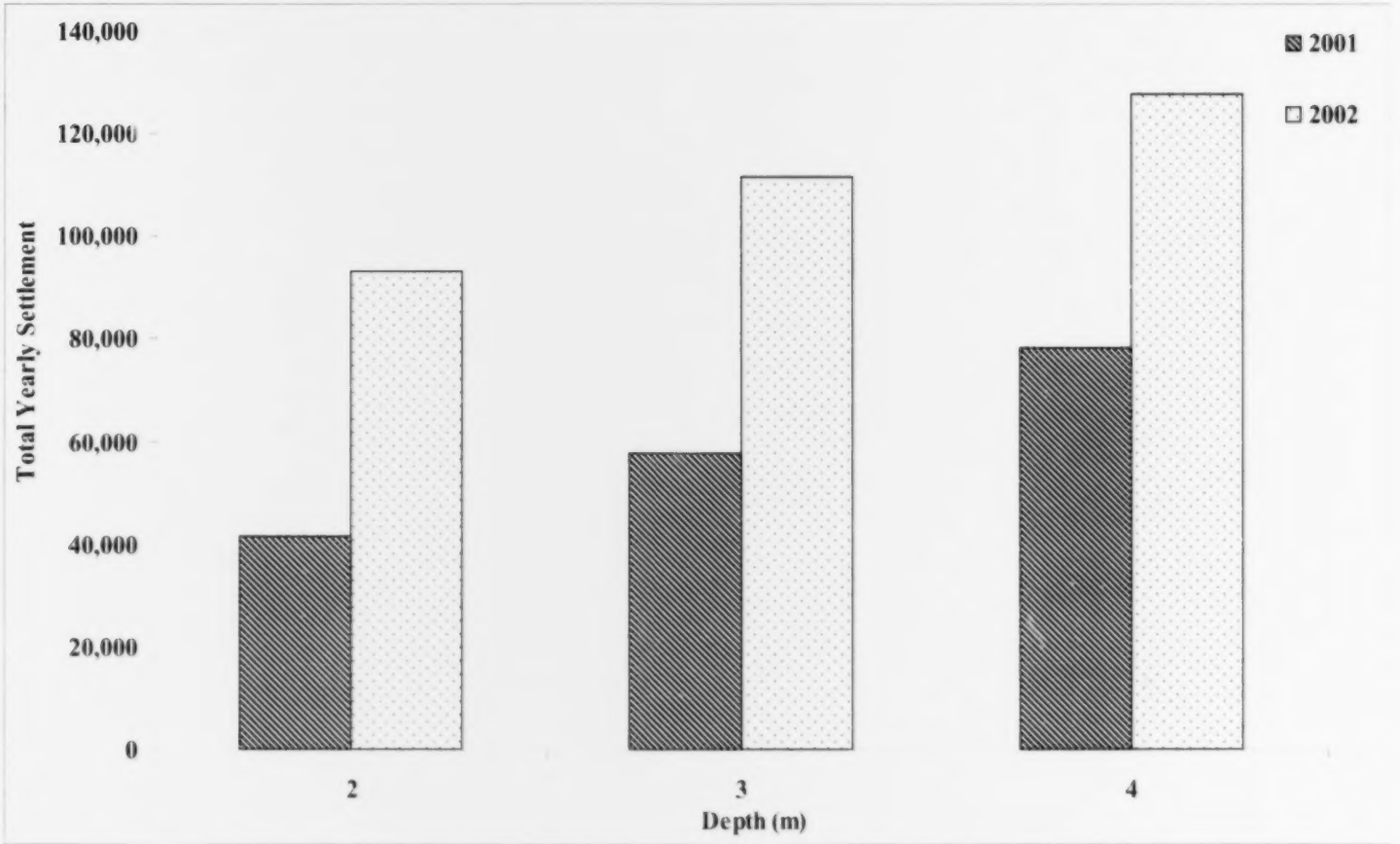

Figure 16: Cumulative yearly mussel spat settlement as a function of depth at Atlantic Silver aquaculture site, Bocabec, NB. Mean of all collectors (n = 6) at depths of 2m, 3m and 4m respectively

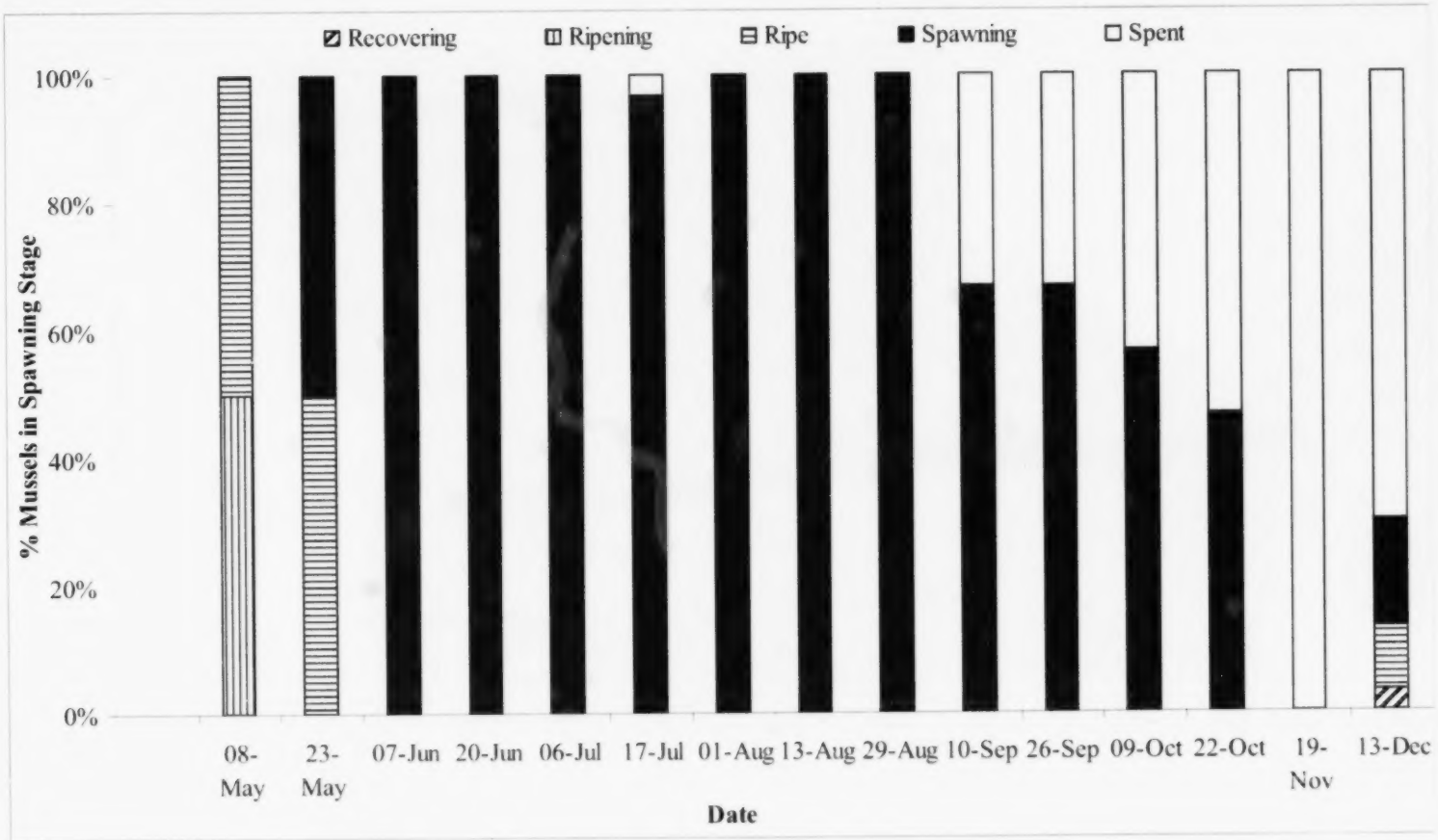

Figure 17: Breakdown of spawning stages in adult mussels (n = 30) collected at the Atlantic Silver aquaculture site in Bocabec Bay, New Brunswick from May to December 2001.

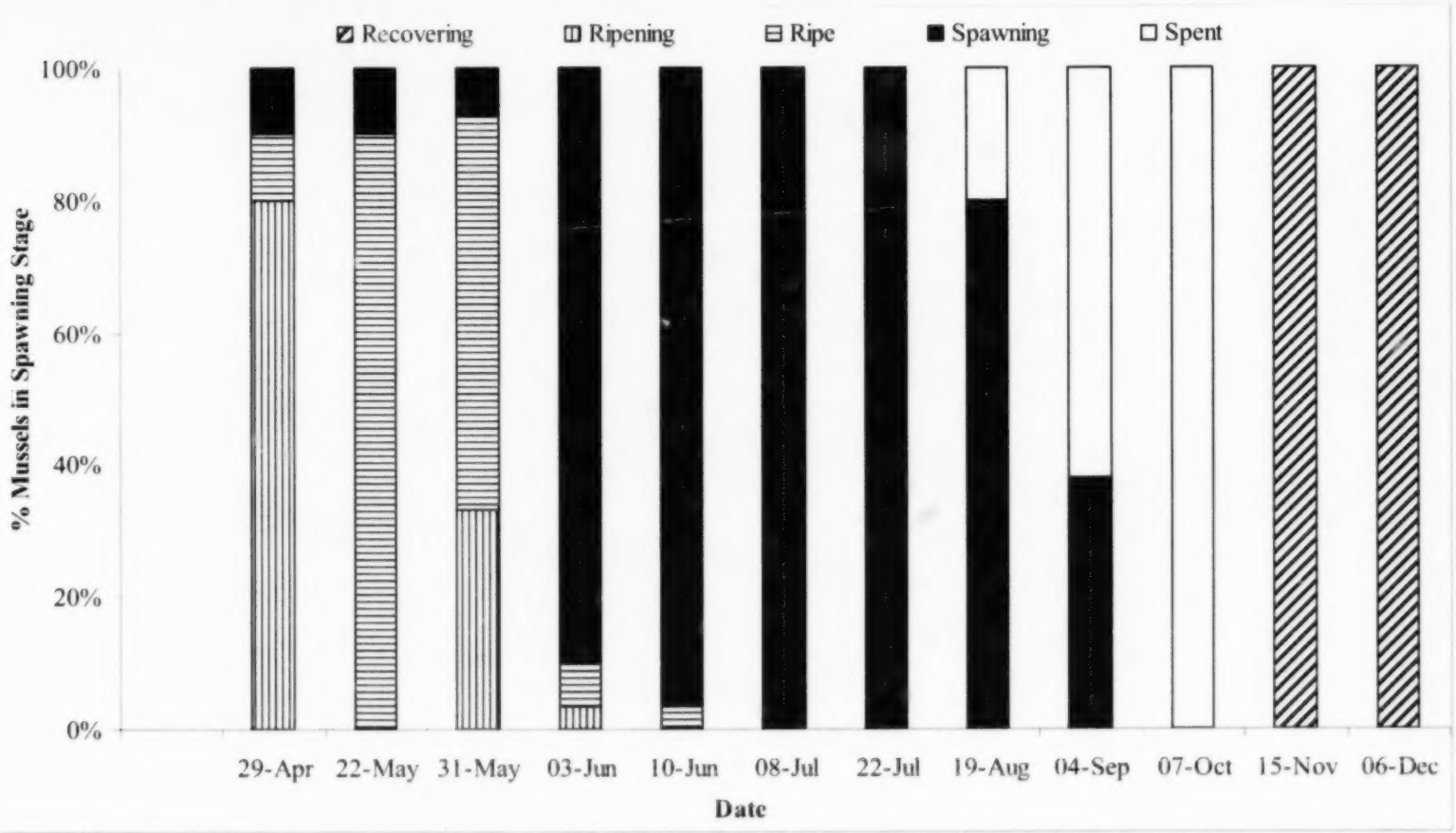

Figure 18: Breakdown of spawning stages in adult mussels (n = 30) collected at the Atlantic Silver aquaculture site in Bocabec Bay, New Brunswick from May to December 2002.

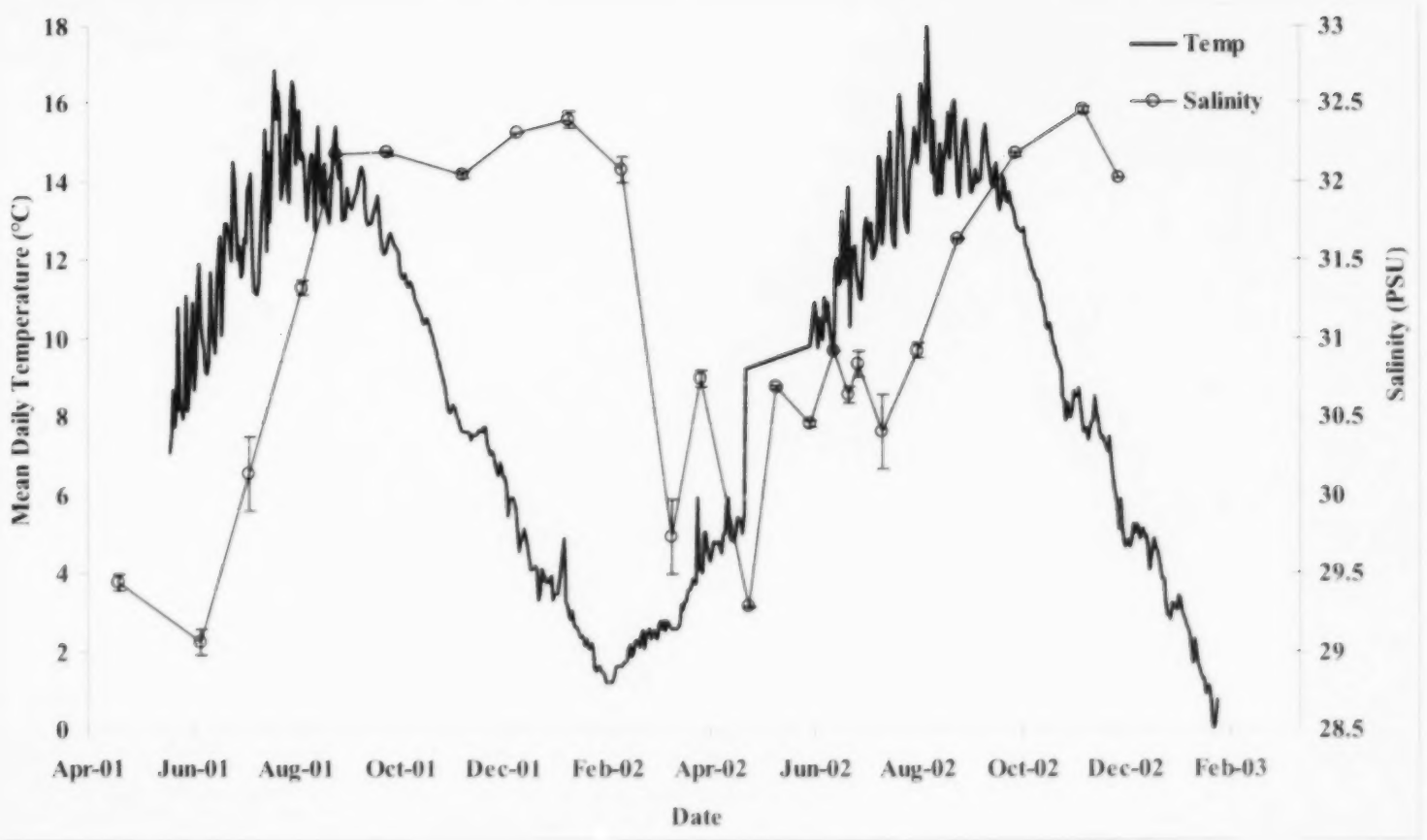

Figure 19: Mean daily water temperatures and salinity measurements at Atlantic Silver salmon aquaculture site in Bocabec Bay, NB. Temperature data collected from May 2001 to Feb. 2003 using a minilog thermograph (interval = 30 min.). Salinity values (mean of 2-6 meter readings) collected using a Seabird CTD from April 2001 to December 2002. Error bars represent one standard error

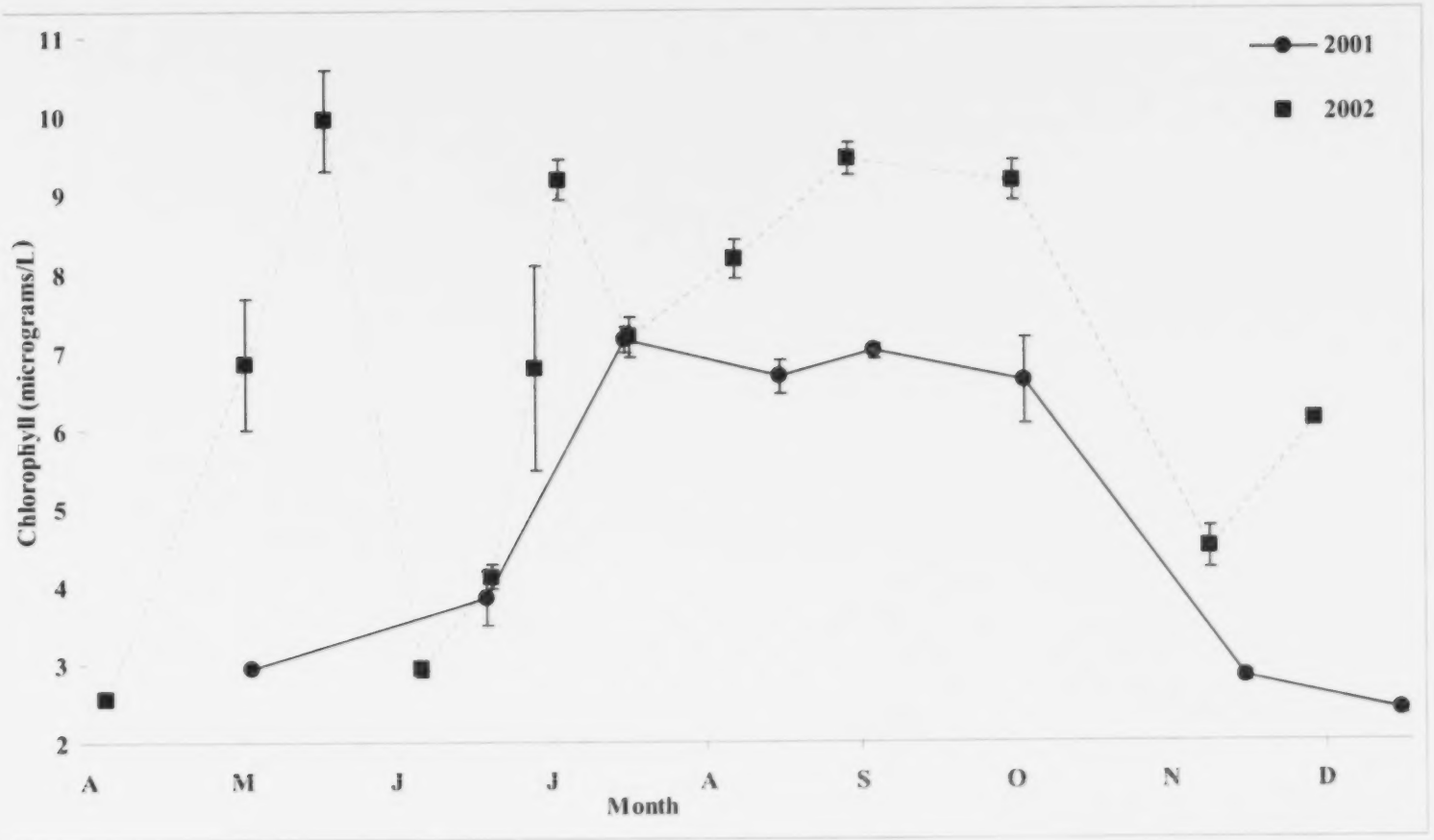

Figure 20: Chlorophyll a values (mean of 2-6 meter readings) collected using a Seabird CTD flourometer, from May 2001 to December 2002 at the Atlantic Silver aquaculture site in Bocabec Bay, New Brunswick. Error bars represent one standard error